

SEE Measurements on the Analog Devices, Inc. AD768 DAC

By

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I. Introduction and Overview

This report describes the testing of a DAC at TAM. This section describes the basics of the test. The description of the TAM test area and facility are contained in section II. Section III contains the test setup and conditions of the test. Section IV contains the results and analyses and the conclusion is in section V.

The purpose of this test was to determine the SEE characteristics of a DAC under heavy ion radiation. The cross section of each device, for both Single Event Upsets (SEU) and Single Event Latch-up (SEL), as a function of ion Linear Energy Transfer (LET) was the primary goal. The SEU and SEL threshold of these devices was also determined. Another observation was any long term or total dose effects from the ion radiation.

A table of the device parameters is shown in Table 1.

Table 1. The devices tested in this study.

Device	Manufacturer	Width	Technology	SNs
AD768	Analog Devices	16 Bit	ABCMOS	7681,7682,7683

Ancillary graphs and comments are in the appendix. Raw data is tabulated and annotated in this section also.

II. Facility Overview

The SEU test facility at Texas A&M cyclotron is located on the campus of the university. DOE and the State of Texas jointly support the facility. Institute staff constructed, and now operate, a K500 superconducting cyclotron and its advanced Electron-Cyclotron Resonance (ECR) ion sources. The facility was designed to provide a user friendly and efficient testing station for SEE studies. The ECR Ion Source is highly charged ions for injection into the cyclotron are produced by electron-ion collisions in magnetically confined plasma excited by microwave radiation. These ions are also used for atomic physics experiments on an adjacent high vacuum beamline.

The cyclotron has a dedicated SEE Testing Facility which is designed for advanced radiation testing of Very Large Scale Integrated (VLSI) circuits, this facility features a large-volume target chamber with a versatile target positioning assembly, and a variety of industry standard vacuum feed through connectors. The chambers upstream from the target chamber provide for the beam control, diagnostic and dosimetry measurements. A large variety of high-energy beams covering a broad range of LET have been developed specifically for this purpose. These beams have a high degree of uniformity over a large cross sectional area. More information can be found at <http://cyclotron.tamu.edu/>.

The accelerator provides a wide range of ions and energies for SEE testing. Ion species can be changed in approximately 180 minutes while ion energies cannot be changed mid-run. The ions interact with the target in an approximately 10^{-4} torr chamber. The chamber can be depressurized and evacuated in approximately 10 minutes when a device change is desired. The beam can also be run in open air if desired. A list of ions used in this study is shown in Table 2.

Table 2.

Particle	Energy(MeV)	InitialLET(Si) (MeV cm ² /mg)	Range μm	LETmax (MeV cm ² /mg)	Range(LETmax) μm
Ne	546	1.74	799	9.65	790
Ar	1000	5.41	500	20.1	491
Kr	2100	19.2	336	41.4	315
Xe	3200	37.9	286	63.4	254

The interior of the chamber is electrically connected to the test area through an airtight bulkhead. The board on which the Devices Under Test (DUTs) reside is mounted on a moveable stage. The DUT maybe be moved in any of three directions. The DUT may also be rotated. A rectangular iris can changed the diameter of the beam from 0.1 cm to 4 cm in either direction. The beam can be completely positioned from the user console and all positioning information can be saved.

The calculation of the beam LET and range in a desired material is done automatically for each run and saved. Other saved information is the energy, fluence, and time of the run as well as the angle. The system recalculates the LET and adjusts for the fluence when the angle is changed. Hardcopies can be made for redundancy. SEU cross-section curves are generated as the experiment proceeds for easy double monitoring of the experiment.

III. Test Setup and Procedure

The test was comprised of two PCs, a power supply, and a specially designed test board. One PC controlled a HP6629A power supply. This allowed precision voltage control and latch-up detection and protection since the PC had millisecond control over the operation of the power supply. Latch-ups were recorded in a separate file.

A dedicated PC controls the test circuit board designed specifically for this test to read and write to the DUTs. This setup allows complete freedom to interact with the DUT. This would allow for any structure in the SEEs or predilection for certain pattern failure or type of SEU to be seen. A depiction of the setup used is shown in Figure 1.

The schematic of the interface DUT board is shown in Figure 2. The voltage outputs of two differential outputs are compared, one under test and one as a reference. The dual DACs structure allows for easy tuning for the threshold of which a voltage interrupt, the primary SEE, can be seen. Resolution down to the LSB could be tested in this manner. The LM308 cascading into a LM311 allowed for ultra-high gain amplification of the output SEE effects.

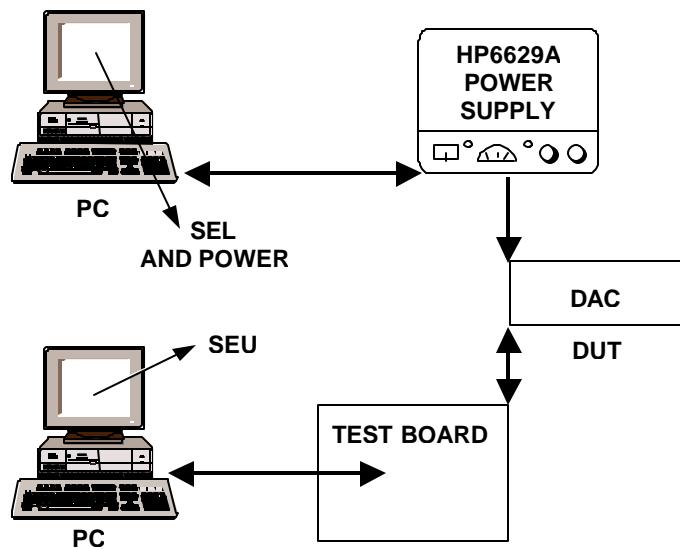


Figure 1. A schematic of the test system.

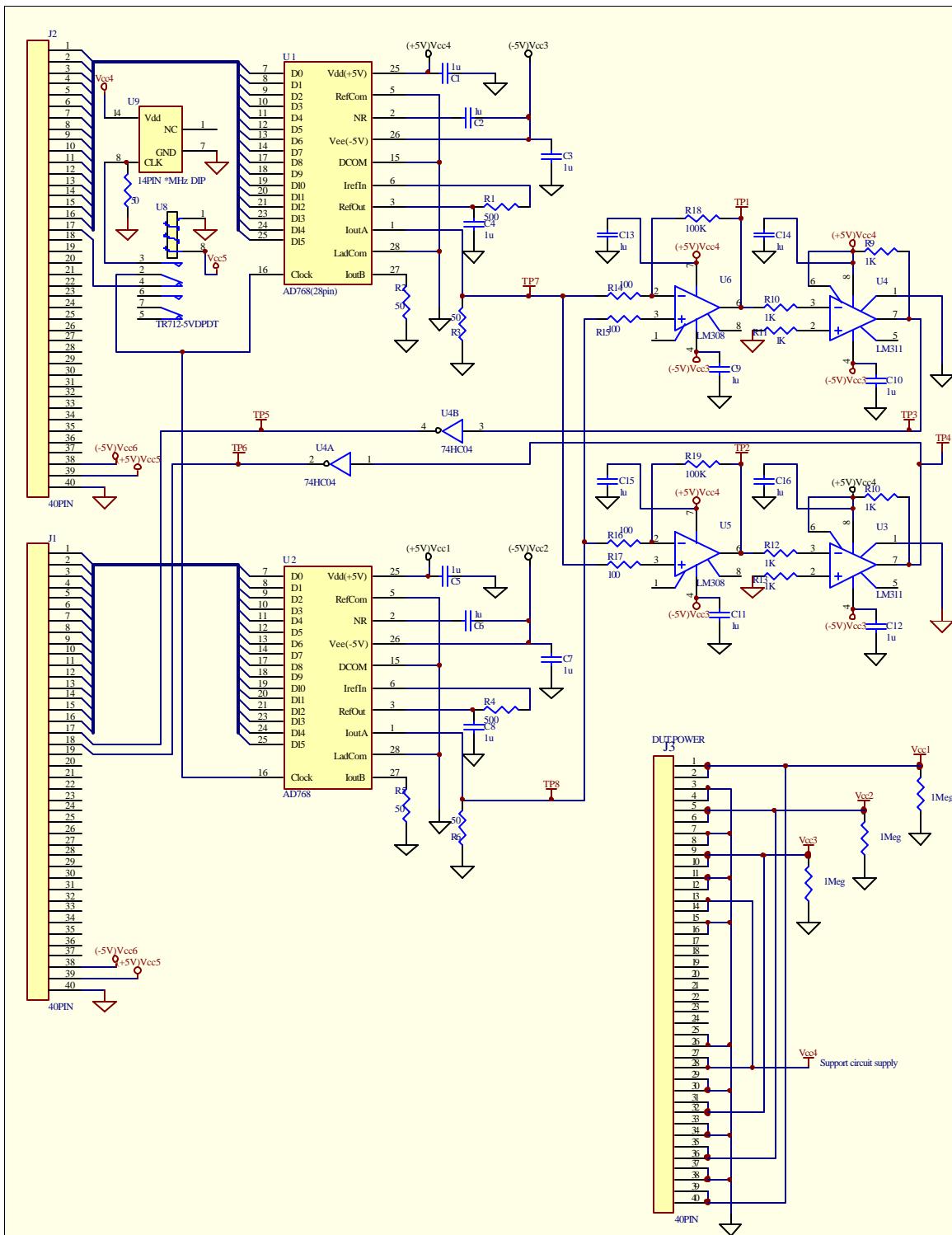


Figure 2. Schematic of the DAC test board.

For this test, most of the radiation runs are done when the DUT is standing by after the proper data has been clocked into the DUT. The PC reads the output of the

board until a DUT SEU is reported, then rewrites the correct pattern to the address and reclocks. All tests were done with the DUT at the lowest or highest voltage and looking for voltage changes up or down, respectively. Some tests were done while reading or writing data to test for susceptibility to SEE during such processes. Other tests were done using various clock speeds, independent of the controlling PC to determine interrupt rate.

The Vdd voltage was always set to 5 volts and the operating temp was approximately 25 °C throughout the study.

IV. Results

Voltage Interrupt SEU

The results of the test of all of the devices are shown in Figure 3. Three devices were tested and there was negligible variation between them. The curve shown in Figure 3 has up to an order of magnitude variation in cross section. Figure 4 shows the results of averaging the data at each redundant LET. The error bars are the standard deviations of the redundant measurements. Figure 5 shows the data divided among the three devices that were tested. All figures are fit a model given by Edmonds ¹. All of these SEU occur in the standby mode. A simple reclocking of the data reset the device.

The device was tested at constant oscillation frequencies of 0.5, 1, and 12 MHz. No SEUs were seen at these frequencies. The device is apparently immune to SEU effects at frequencies over 0.5 MHz.

SEL

The device showed no Single Event Latchups at any LET. LETs up to 120 Mev-cm²/mg were tested. Extreme angles and lower energy ions, which should have experienced end of range phenomenon in the sensitive volume, did not trigger latchup.

Damage Due to Ions

¹ Edmonds, L.D., *SEU Cross Sections Derived From A Diffusion Analysis*, , IEEE Transactions on Nuclear Science, Volume: 43 Issue: 6 Part: 2 , Dec. 1996 Page(s): 3207 -3217



The three devices experienced 100 krad(Si), 62 krad(Si), and 290 krad(Si) with various LET ions. No operation abnormalities were seen with heavy ions.

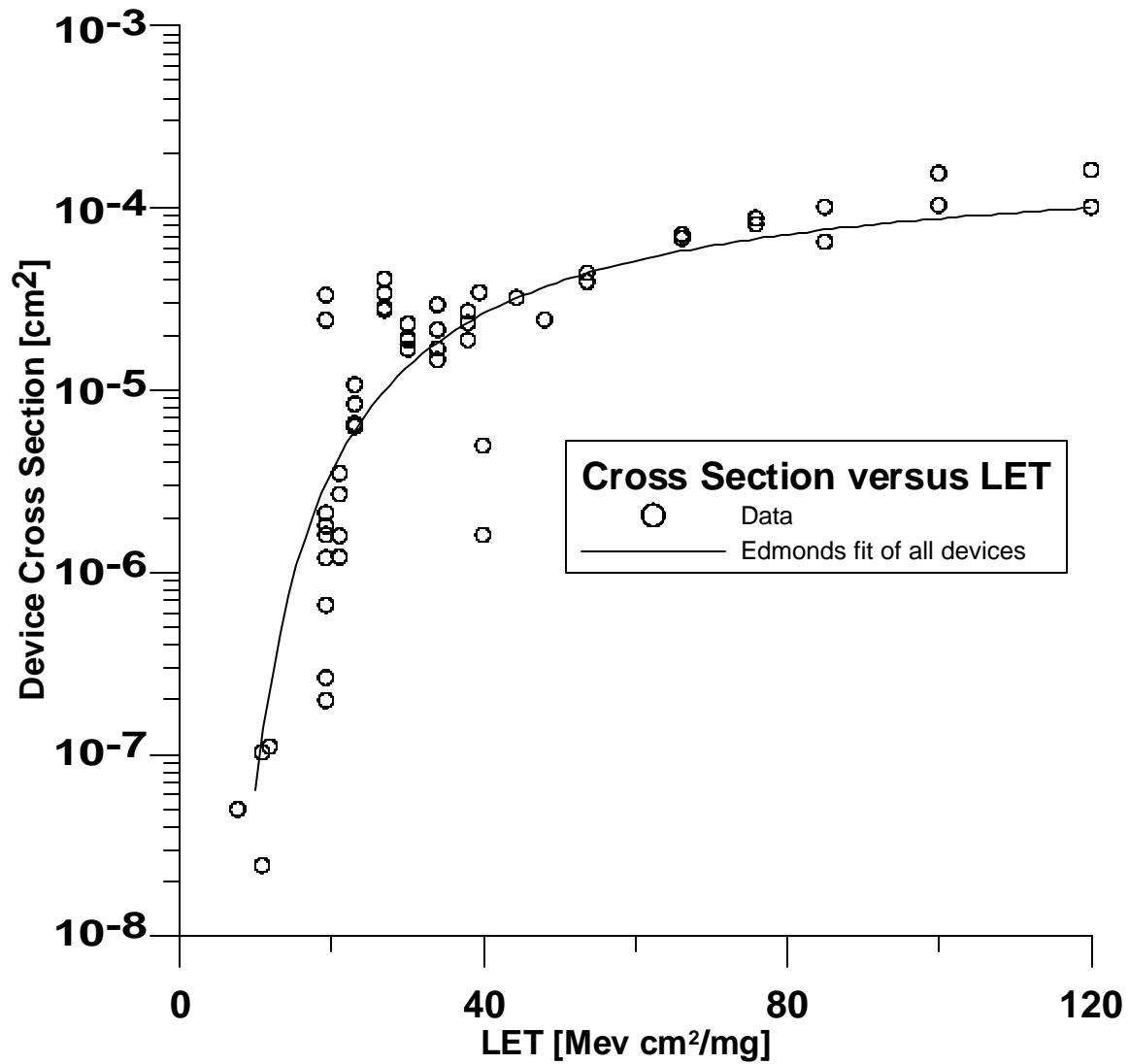


Figure 3

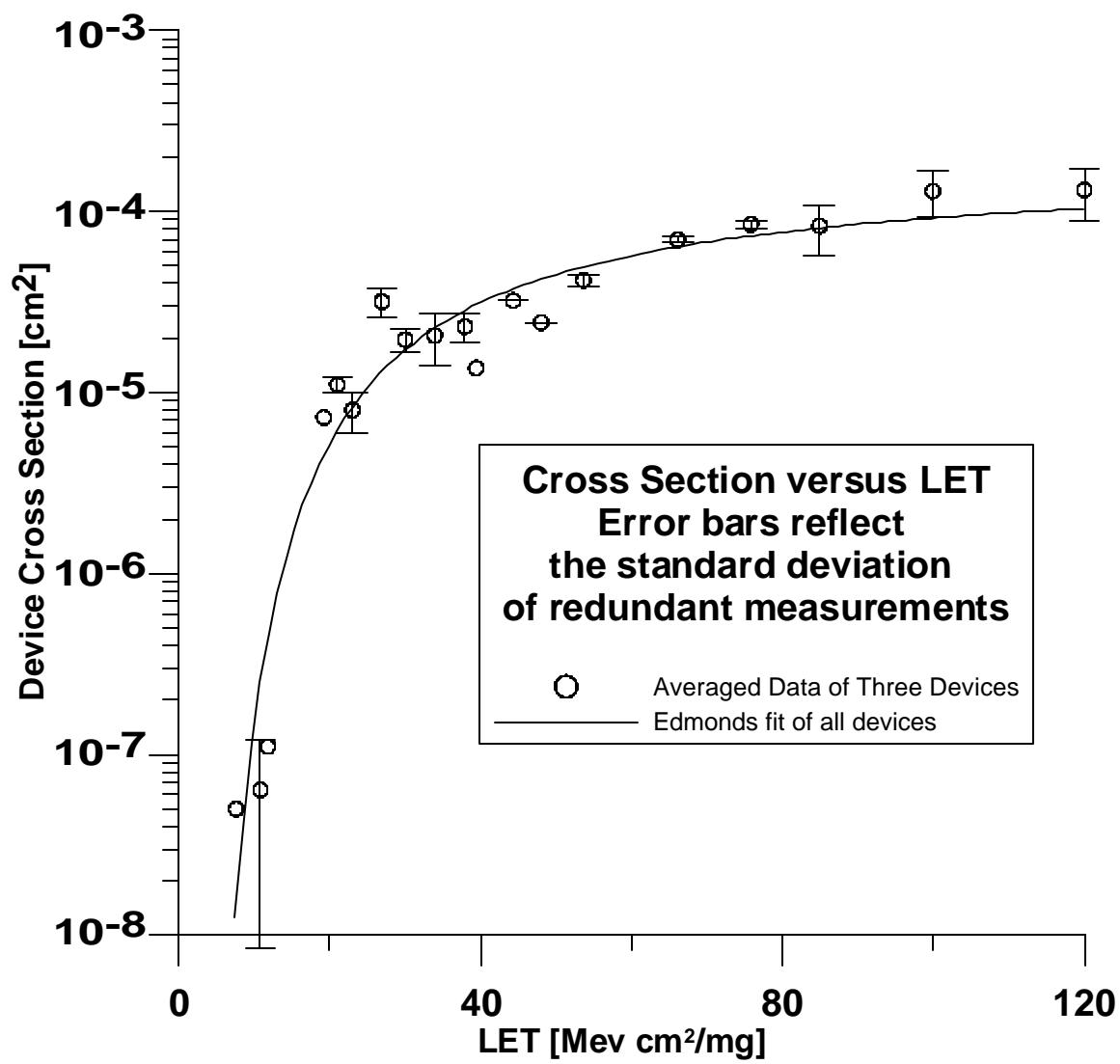


Figure 4

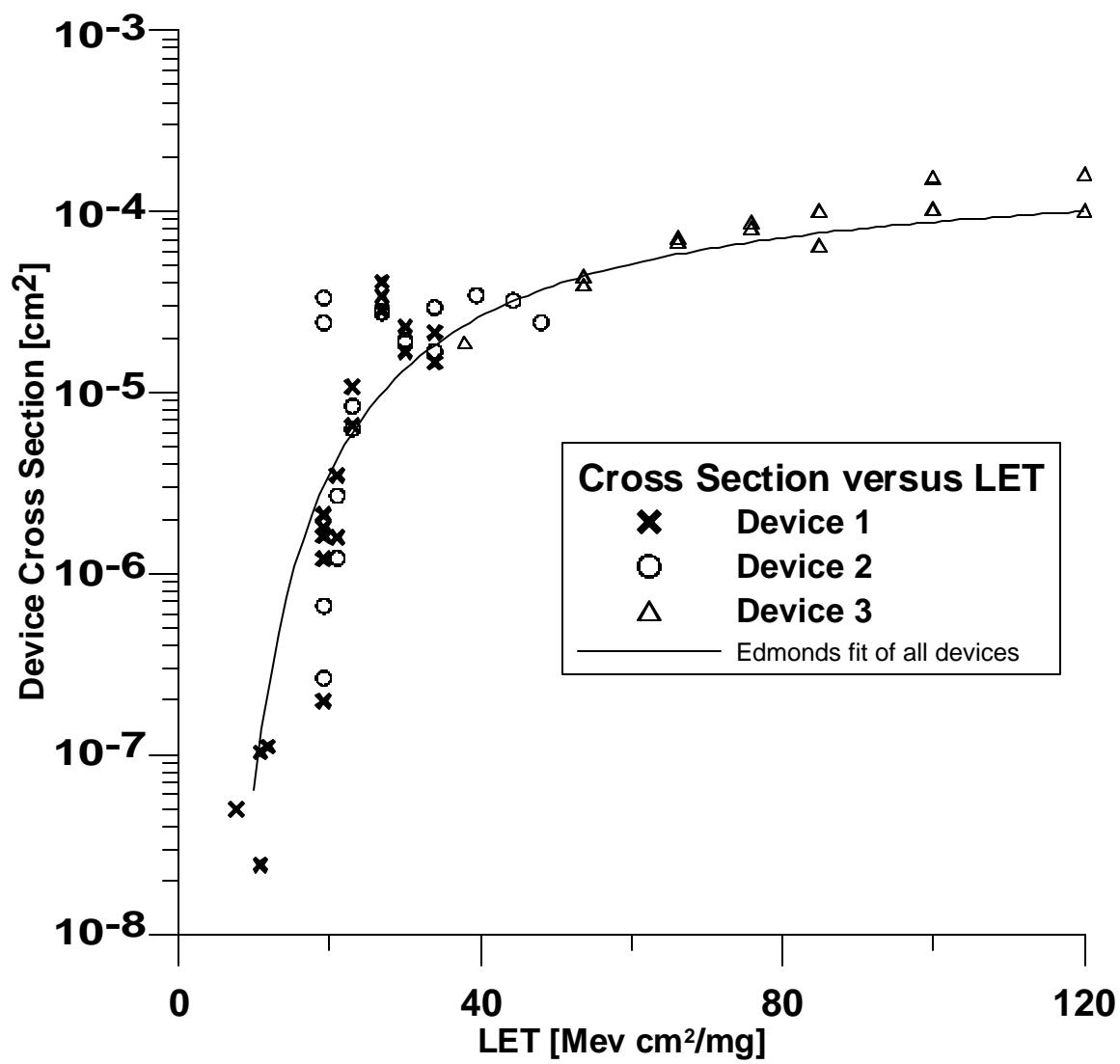


Figure 5

V. Conclusion

These devices are apparently very SEU hard and SEL immune for most space applications. Constant clocking eliminates the voltage interrupt SEU completely. These devices should be error free in an application in which they are constantly clocked at frequencies more than 500 kHz. The results of the testing are shown in Table 3.

Table 3.

Device	Clocking Over 500 kHz	SEL Threshold (MeV cm ² /mg)	SEU Threshold (MeV cm ² /mg)	SEU Saturation Device Cross- section[cm ²]
AD768	Yes	>120	N/A	N/A
AD768	No	>120	7.5	1.91e-4

Appendix

Raw Data:

The following sheets contain the raw data generated from the 0600 TAM exposure. No inference should be made without discussing it with Leif Scheick, the engineer who oversaw the exposure. The data interpolates and extrapolates very well to all LET values; i.e. the data is very consistent.

Run #	Test run file	De vic	S/N	SE U	SE L	Ion m	Bea flux (Me V/u)	Avg. Total fluence	DU T	Flux ang le	Eff. fluence	Re s der	Al act	Imp der	Eff. LET(r(Si))	Eff. LETeff
508	jpl060 0.tE3	D U	A D	Kr T2	25 78 0	247000	14300000	-45			1.0E+07	359	0	0	0	0
411	jpl060 0.tBE	A D	0 76 8	Ar T2	25 76 8	873000	9720000	0	8.0E+06	9.7E+06	3	0	999	5.42	500	5.42
412	jpl060 0.tBF	A D	0 76 8	Ar T2	25 76 8	855000	100000000	0	8.0E+06	1.0E+08	3	0	999	5.42	500	5.42
415	jpl060 0.tBI	A D	5 76 8	Ar T2	25 76 8	822000	100000000	0	8.0E+06	1.0E+08	0	236	613	7.6	237	7.6
413	jpl060 0.tBG	A D	0 76 8	Ar T2	25 76 8	852000	87300000	0	8.0E+06	8.7E+07	3	357	335	10.8	102	10.8
414	jpl060 0.tBH	A D	5 76 8	Ar T2	25 76 8	786000	70600000	0	8.0E+06	7.1E+07	5	357	335	10.8	102	10.8
417	jpl060 0.tBK	A D	0 76 8	Ar T2	25 76 8	817000	100000000	0	8.2E+05	1.0E+08	5	357	335	10.8	102	10.8
418	jpl060 0.tBL	A D	0 76 8	Ar T2	25 76 8	794000	100000000	0	8.2E+05	1.0E+08	5	357	335	10.8	102	10.8
419	jpl060 0.tBM	A D	0 76 8	Ar T2	25 76 8	830000	100000000	0	8.2E+05	1.0E+08	5	357	335	10.8	102	10.8
420	jpl060 0.tBN	A D	0 76 8	Ar T2	25 76 8	854000	100000000	0	8.2E+05	1.0E+08	5	357	335	10.8	102	10.8
421	jpl060 0.tBO	A D	2 76 8	Ar T2	25 76 8	837000	99800000	0	8.2E+05	1.0E+08	3	357	335	10.8	102	10.8
422	jpl060 0.tBP	A D	0 76 8	Ar T2	25 76 8	836000	100000000	0	8.4E+05	1.0E+08	3	357	335	10.8	102	10.8
423	jpl060 0.tBQ	A D	9 76 8	Ar T2	25 76 8	839000	110000000	24. 51	8.3E+06	1.0E+08	3	357	335	11.8	93	11.8

416	jpl060 0.tBJ	A D 76 8	0	Ar	25	354000	99900000	0	8.2E+05	1.0E+08	5	411	158	14.8	41	14.8
461	jpl060 0.tCS	A D 76 8	0	0 Kr	25	51500	4990000	0	5.3E+04	5.0E+06	8	0	209 8	19.2	336	19.2
462	jpl060 0.tCT	A D 76 8	6	0 Kr	25	178000	10000000	0	5.3E+04	1.0E+07	8	0	209 8	19.2	336	19.2
463	jpl060 0.tCU	A D 76 8	0	0 Kr	25	181000	10000000	0	5.3E+04	1.0E+07	8	0	209 8	19.2	336	19.2
464	jpl060 0.tCV	A D 76 8	0	0 Kr	25	189000	10000000	0	5.3E+04	1.0E+07	8	0	209 8	19.2	336	19.2
465	jpl060 0.tCW	A D 76 8	1	0 Kr	25	182000	10100000	0	5.3E+04	1.0E+07	8	0	209 8	19.2	336	19.2
466	jpl060 0.tCX	A D 76 8	8	0 Kr	25	210000	9940000	0	1.0E+05	9.9E+06	8	0	209 8	19.2	336	19.2
467	jpl060 0.tCY	A D 76 8		Kr	25	0	0	0	1.0E+05	0.0E+00	8	0	209 8	19.2	336	19.2
468	jpl060 0.tCZ	A D 76 8	9	0 Kr	25	213000	10000000	0	1.0E+05	1.0E+07	8	0	209 8	19.2	336	19.2
469	jpl060 0.tD0	A D 76 8	0	0 Kr	25	216000	9970000	0	1.0E+05	1.0E+07	8	0	209 8	19.2	336	19.2
470	jpl060 0.tD1			Kr	25	188000	75300	0		7.5E+04	0	0	209 8	19.2	336	19.2
471	jpl060 0.tD2	A D 76 8	16	0 Kr	25	201000	10100000	0	1.0E+05	1.0E+07	4	0	209 8	19.2	336	19.2
489	jpl060 0.tDK	D A U D T2 76 0	5	0 Kr	25	221000	10100000	0	1.8E+05	1.0E+07	4	0	209 8	19.2	336	19.2
490	jpl060 0.tDL	D A U D T2 76 0	2	0 Kr	25	236000	10100000	0	1.8E+05	1.0E+07	4	0	209 8	19.2	336	19.2
509	jpl060 0.tE4	D A U D T2 78 0		Kr	25	260000	9930000	0		9.9E+06	0	0	209 8	19.2	336	19.2
510	jpl060 0.tE5	D A U D T2 78 0	189	0 Kr	25	235000	10100000	0	2.0E+05	1.0E+07	7	0	209 8	19.2	336	19.2
511	jpl060 0.tE6	D A U D T2 78 0	136	0 Kr	25	255000	9990000	0	2.0E+05	1.0E+07	7	0	209 8	19.2	336	19.2
512	jpl060 0.tE7	D A U D T2 78 0		Kr	25	260000	2840000	0	2.0E+05	2.8E+06	7	0	209 8	19.2	336	19.2

484	jpl060	A	12	0	Kr	25	205000	10100000	0	1.8E+05	1.0E+07	4	58	179	8	21	272	21	
		D																	
		76																	
		8																	
485	jpl060	A	26	0	Kr	25	195000	9920000	0	1.8E+05	9.9E+06	4	58	179	8	21	272	21	
		D																	
		76																	
		8																	
491	jpl060	D	A	9	0	Kr	25	226000	9890000	0	1.8E+05	9.9E+06	4	58	179	8	21	272	21
		U	D																
		T2	76																
		0																	
492	jpl060	D	A	20	0	Kr	25	228000	9930000	0	1.8E+05	9.9E+06	4	58	179	8	21	272	21
		U	D																
		T2	76																
		0																	
477	jpl060	A	80	0	Kr	25	183000	9960000	0	1.8E+05	1.0E+07	4	105	152	7	23	219	23	
		D																	
		76																	
		8																	
478	jpl060	A	49	0	Kr	25	188000	9990000	0	1.8E+05	1.0E+07	4	105	152	7	23	219	23	
		D																	
		76																	
		8																	
493	jpl060	D	A		Kr	25	231000	10000000	0	2.0E+05	1.0E+07	6	105	152	7	23	219	23	
		U	D																
		T2	78																
		0																	
494	jpl060	D	A	53	0	Kr	25	230000	10100000	0	2.0E+05	1.0E+07	6	105	152	7	23	219	23
		U	D																
		T2	78																
		0																	
495	jpl060	D	A	39	0	Kr	25	224000	9910000	0	2.0E+05	9.9E+06	6	105	152	7	23	219	23
		U	D																
		T2	78																
		0																	
472	jpl060	A	203	0	Kr	25	106000	9950000	0	1.0E+05	1.0E+07	8	169	111	7	26.9	147	26.9	
		D																	
		76																	
		8																	
473	jpl060	A	0	0	Kr	25	102000	9970000	0	1.0E+05	1.0E+07	8	169	111	7	26.9	147	26.9	
		D																	
		76																	
		8																	
474	jpl060	A	0	0	Kr	25	103000	10000000	0	1.0E+05	1.0E+07	4	169	111	7	26.9	147	26.9	
		D																	
		76																	
		8																	
475	jpl060	A	213	0	Kr	25	102000	10000000	0	1.0E+05	1.0E+07	4	169	111	7	26.9	147	26.9	
		D																	
		76																	
		8																	
476	jpl060	A	255	Kr		25	103000	10000000	0	1.0E+05	1.0E+07	4	169	111	7	26.9	147	26.9	
		D																	
		76																	
		8																	
496	jpl060	D	A	174	0	Kr	25	111000	10000000	0	2.0E+05	1.0E+07	6	170	111	4	26.9	147	26.9
		U	D																
		T2	78																
		0																	
497	jpl060	D	A	172	0	Kr	25	101000	10000000	0	2.0E+05	1.0E+07	6	170	111	4	26.9	147	26.9
		U	D																
		T2	78																
		0																	
479	jpl060	A	126	0	Kr	25	190000	10000000	0	1.8E+05	1.0E+07	4	204	860		30	108	30	
		D																	
		76																	
		8																	
480	jpl060			Kr	25	0	0	0	0	0.0E+00	0	204	860		30	108	30		
		0																	
		DB																	



481	jpl060	A	175	0	Kr	25	221000	10100000	0	1.8E+05	1.0E+07	4	204	860	30	108	30		
	0.tDC	D		D		76													
				8															
498	jpl060	D	A	117	0	Kr	25	229000	9970000	0	2.0E+05	1.0E+07	6	204	860	30	108	30	
	0.tDT	U	D		D		T2	78											
				0															
499	jpl060	D	A	121	0	Kr	25	256000	9980000	0	2.0E+05	1.0E+07	6	204	860	30	108	30	
	0.tDU	U	D		D		T2	78											
				0															
482	jpl060	A	109	0	Kr	25	222000	9900000	0	1.8E+05	9.9E+06	4	238	584	33.9	71	33.9		
	0.tDD	D		D		76													
				8															
483	jpl060	A	161	0	Kr	25	227000	10000000	0	1.8E+05	1.0E+07	4	238	584	33.9	71	33.9		
	0.tDE	D		D		76													
				8															
500	jpl060	D	A	95	0	Kr	25	251000	10000000	0	2.0E+05	1.0E+07	7	238	584	33.9	71	33.9	
	0.tDV	U	D		D		T2	78											
				0															
501	jpl060	D	A	167	0	Kr	25	261000	10100000	0	2.0E+05	1.0E+07	7	238	584	33.9	71	33.9	
	0.tDW	U	D		D		T2	78											
				0															
505	jpl060	D	A		Kr	25	266000	11400000	-30				9.9E+06	0	204	860	34.6	94	34.6
	0.tE0	U	D		D		T2	78											
				0															
678	jpl060	A	19	0	Xe	24.	42000	1020000	0	4.4E+04	1.0E+06	5	0	319	37.9	286	37.9		
	0.tIT	D		D		2								7					
				76															
679	jpl060	A	16	0	Xe	24.	36600	995000	0	3.6E+04	1.0E+06	5	0	319	37.9	286	37.9		
	0.tIU	D		D		2								7					
				76															
699	jpl060		0	0	Xe	24.	24900	2010000	0				2.0E+06	0	0	319	37.9	286	37.9
	0.tJE	A		D		8									7				
700	jpl060	A	42	0	Xe	24.	18900	2230000	0				2.2E+06	0	0	319	37.9	286	37.9
	0.tJF	D		D		8									7				
506	jpl060	D	A		Kr	25	239000	13100000	-40				1.0E+07	0	204	860	39.2	83	39.2
	0.tE1	U	D		D		T2	78											
				0															
502	jpl060	D	A	195	0	Kr	25	255000	11700000	-30.	2.0E+05	1.0E+07	7	238	584	39.4	61	39.4	
	0.tDX	U	D		D		T2	78		49									
				0															
486	jpl060		0	0	Xe	24.	267000	4810000	0				4.8E+06	0	271	269	39.9	34	39.9
	0.tDH	A		D		8													
487	jpl060	A	37	0	Kr	25	265000	9930000	0	1.8E+05	9.9E+06	4	271	269	39.9	34	39.9		
	0.tDI	D			D	76													
				8															
488	jpl060	A	12	0	Kr	25	268000	9980000	0	1.8E+05	1.0E+07	4	271	269	39.9	34	39.9		
	0.tDJ	D		D		76													
				8															
507	jpl060	D	A		Kr	25	247000	14000000	-45				9.9E+06	0	204	860	42.4	77	42.4
	0.tE2	U	D		D		T2	78											
				0															
503	jpl060	D	A	180	0	Kr	25	263000	13000000	-40	2.0E+05	1.0E+07	7	238	584	44.3	54	44.3	
	0.tE3	U	D		D	76													
				0															



	0.tDY	U	D																
	T2	78		0															
504	jpl060	D	A	138	0	Kr	25	265000	14200000	-45	2.0E+05	1.0E+07	7	238	584	48	50	48	
	0.tDZ	U	D	T2	78		0												
680	jpl060	A	81	0	Xe	24.	8	36800	4230000	45		3.0E+06	5	0	319	53.6	202	53.6	
	0.tIV	D	2			76	8												
681	jpl060	A	91	0	Xe	24.	8	26100	4250000	45		3.0E+06	5	0	319	53.6	202	53.6	
	0.tIVV	D	2			76	8												
682	jpl060	A	76	0	Xe	24.	8	31200	2840000	55		1.6E+06	5	0	319	66.1	164	66.1	
	0.tIX	D	2			76	8												
683	jpl060	A	98	0	Xe	24.	8	34600	3480000	55		2.0E+06	5	0	319	66.1	164	66.1	
	0.tIY	D	2			76	8												
684	jpl060	A	112	0	Xe	24.	8	36300	4000000	60		2.0E+06	5	0	319	75.8	143	75.8	
	0.tIZ	D	2			76	8												
685	jpl060	A	120	0	Xe	24.	8	34300	3990000	60		2.0E+06	5	0	319	75.8	143	75.8	
	0.tJ0	D	2			76	8												
690	jpl060	A	89	0	Xe	24.	8	31300	2820000	45		2.0E+06	5	203	737	84.9	42	84.9	
	0.tJ5	D	2			76	8												
691	jpl060	A	138	0	Xe	24.	8	30900	2820000	45		2.0E+06	5	203	737	84.9	42	84.9	
	0.tJ6	D	2			76	8												
692	jpl060				Xe	24.		0		0	45		0.0E+00	0	203	737	84.9	42	84.9
	0.tJ7																		
693	jpl060	A	0	0	Xe	24.	8	27900	2840000	45		2.0E+06	5	203	737	84.9	42	84.9	
	0.tJ8	D	2			76	8												
694	jpl060	A	0	0	Xe	24.	8	28900	2840000	45		2.0E+06	5	203	737	84.9	42	84.9	
	0.tJ9	D	2			76	8												
695	jpl060	A	0	0	Xe	24.	8	27500	2830000	45		2.0E+06	0	203	737	84.9	42	84.9	
	0.tJA	D	2			76	8												
696	jpl060	A	0	0	Xe	24.	8	28500	8580000	45		6.1E+06	0	203	737	84.9	42	84.9	
	0.tJB	D	2			76	8												
697	jpl060	A	0	0	Xe	24.	8	24000	4380000	45		3.1E+06	0	203	737	84.9	42	84.9	
	0.tJC	D	2			76	8												



	0.tJC	D		8																
		2																		
		76																		
		8																		
686	jpl060	A	142	0 Xe	24.	29000	4000000	60		2.0E+06	5	138	165	99.9	66	99.9				
	0.tJ1	D			8															
		2																		
		76																		
		8																		
687	jpl060	A	213	0 Xe	24.	29100	4010000	60		2.0E+06	5	138	165	99.9	66	99.9				
	0.tJ2	D			8															
		2																		
		76																		
		8																		
688	jpl060	A	223	0 Xe	24.	29400	4010000	60		2.0E+06	5	203	737	120	30	120				
	0.tJ3	D			8															
		2																		
		76																		
		8																		
689	jpl060	A	139	0 Xe	24.	31800	4000000	60		2.0E+06	5	203	737	120	30	120				
	0.tJ4	D			8															
		2																		
		76																		
		8																		
698	jpl060	A	0	0 Xe	24.	24600	4110000	60		2.1E+06		203	737	120	30	120				
	0.tJD	D			8															
		2																		
		76																		
		8																		